Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 595 191 A1

EUROPEAN PATENT APPLICATION

(21) Application number: 93117028.6

(22) Date of filing: 21.10.93

(51) Int. Cl.5: H02J 7/14

(30) Priority: 28.10.92 IT TO920876

(43) Date of publication of application: 04.05.94 Bulletin 94/18

(84) Designated Contracting States: DE ES FR GB SE

(71) Applicant: INDUSTRIE MAGNETI MARELLI S.p.A.
Via Griziotti, 4
I-20145 Milano(IT)

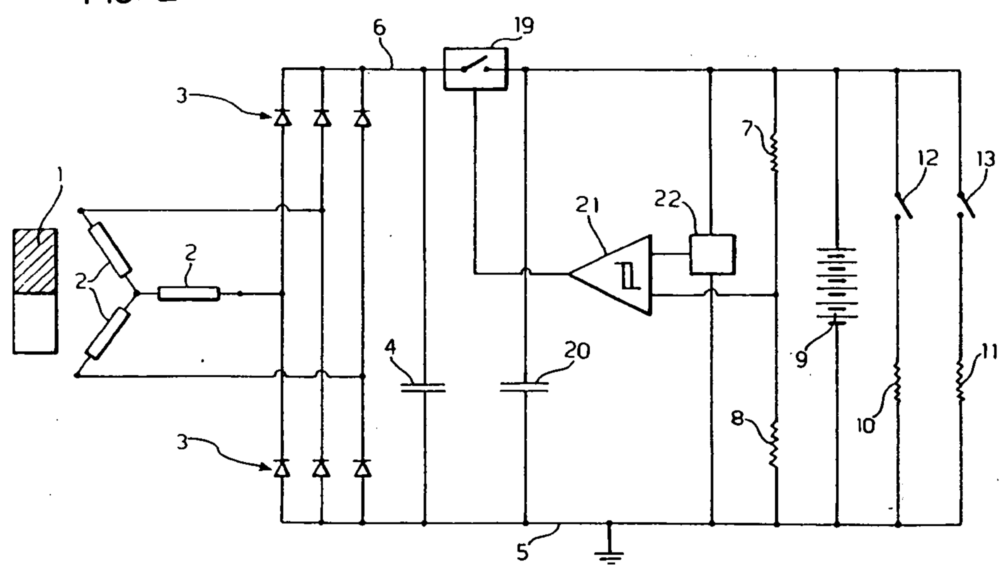
(72) Inventor: Fasola, Giancarlo, c/o IND. MAGNETI MARELLI S.p.A.
Via Griziotti, 4
I-20145 Milano(IT)
Inventor: Navarra, Pietro
Via Popoli Uniti, 13
I-20093 Cologno Monzese (Milano)(IT)

(74) Representative: Bosotti, Luciano et al
c/o Jacobacci-Casetta & Perani S.p.A.
Via Alfieri, 17
I-10121 Torino (IT)

(54) A voltage regulator for an electrical generator, particularly an alternator.

(57) A voltage regulator for an alternator with excitation by permanent magnets (1) uses a supercapacitor (20) with a capacitance of the order of one farad and a static or mechanical switch (19) with a variable switching frequency of the order of tens of Hz. The device has the advantage that it is free of radio-frequency emissions and is also simpler, lighter and less bulky than voltage regulators formed according to the prior art.

FIG. 2



EP 0 595 191 A1

The present invention relates to a voltage regulator usable in particular in association with an electrical generator in a vehicle having an internal combustion engine.

Typically, an electrical generator for vehicles is constituted by a synchronous, rotary electrical machine, normally an alternator, and by a multiphase rectifier bridge for outputting a direct electrical current.

The voltage-regulator circuits according to the prior art use conventional semiconductor circuits or switching regulator circuits such as, for example, that described in the present Applicant's European patent appln. No. 90830291.2 filed on 26th June 1990. This application describes a voltage-regulator circuit which uses a switching regulator with a working frequency of about 40 kHz, regulated by pulse-amplitude modulation.

For a better understanding of the present invention, this circuit of the prior art will now be described in greater detail with reference to Figure 1.

Figure 1 shows an alternator constituted by a permanent-magnet inductor 1 and an armature constituted by windings 2. The windings 2 are connected to a three-phase rectifier bridge of which the rectifier elements, indicated 3, are diodes. A capacitor 4, connected to the output of the rectifier bridge between the positive terminal 6 and the negative terminal 5 which, typically, is connected to the earth of the vehicle, has the purpose of smoothing the waveform of the voltage output by the rectifier bridge.

The voltage across the capacitor 4, which is the voltage output from the rectifier bridge, depends on the rate of rotation of the alternator which in turn depends on the rate of rotation of the internal combustion engine of the vehicle. Clearly, therefore, the voltage across the capacitor 4 is variable according to the rate of rotation of the engine and, in many cases, is too high to be applied to the battery 9 of the vehicle. It is therefore necessary to interpose between the rectifier bridge and the battery 9 a voltage regulator, the function of which is to reduce the voltage to a value suitable for the battery 9.

In the known circuit at present under examination, the voltage regulator is constituted by a switching circuit in a configuration known as a step-down configuration. A switch, typically a MOS transistor, with controlled switching, that is, into the cut-off condition or into the fully-conductive (saturated) condition, is connected to the positive pole 6 of the rectifier bridge. A coil 17 is connected to the output of the transistor 15 and is connected in turn to the positive terminal of the battery 9. The cathode of a rectifier diode 16 is also connected to the output of the transistor 15 and its anode is connected to earth.

When the transistor 15 is conducting, a current flows from the positive terminal 6 of the rectifier bridge through the transistor 15 and the coil 17 towards the battery 9 and any users 10, 11 in the vehicle which can be connected or disconnected by means of the corresponding switches 12, 13.

The current supplied also charges a capacitor 18 connected in parallel with the battery 9. At this stage, the current flowing stores energy in the coil 17. When the transistor 15 is cut off, the capacitor 18 maintains the voltage to the battery 9 and the loads 10 and 11 whilst the energy stored in the coil 17 causes current to be recycled from earth 5 through the diode 16.

The transistor 15 is controlled so as to be cut off or made fully conductive (saturated) by a control circuit 14 operating with pulse-amplitude modulation. The control circuit 14 achieves the regulation by detecting the voltage across the capacitor 18 by means of a connection to the intermediate junction of a voltage divider which is constituted by resistances 7 and 8 and is connected in parallel with the capacitor 18 and the battery 9.

Typically, the value detected at the intermediate junction of the voltage divider 7, 8 is compared with a reference voltage generated within the control circuit 14. The switching frequency of the transistor reaches values of about 40 kHz.

The regulator circuit described above has some technical disadvantages.

A first disadvantage is due to the radio-frequency electromagnetic emissions caused by the high frequency at which the transistor 15 is switched (40 kHz). A second disadvantage is due to the complexity of the circuit and to its cost and bulk.

The object of the present invention is to provide a voltage regulator which solves all the problems mentioned above in a satisfactory manner and, in particular, which provides a simpler and less bulky regulator which is completely free of radio-frequency electromagnetic emissions.

According to the present invention, this object is achieved by virtue of a voltage regulator having the characteristics indicated in the claims which follow the present description.

Further advantages and characteristics of the present invention will become clear from the following detailed description which is given with the aid of the appended drawings, provided by way of non-limiting example, in which:

Figure 1 has already been described with reference to the prior art,

Figure 2 is a circuit diagram of an embodiment of the present invention, and

Figure 3 is a cartesian graph illustrating the operation of the present invention.

An embodiment of the present invention will now be described with reference to Figure 2. In Figure 2, parts and elements already described with reference to Figure 1 have again been given the same numerical symbols.

A capacitor 4 is connected to the output of the rectifier bridge, between the positive terminal 6 and the earth terminal 5. The capacitor 4 has a capacitance of several hundreds of microfarads and its function is mainly to limit the voltage peaks which occur during the opening of a controlled switch 19 interposed between the positive terminal 6 and the battery 9. The opening and closing of the switch 19 are controlled by a control circuit 21 which is essentially a voltage comparator.

The voltage comparator 21 compares a reference voltage generated in known manner by a reference-voltage generator 22 with a voltage detected at the intermediate junction of a voltage divider which is constituted by the resistances 7 and 8 and is disposed in parallel with the battery 9. In practice, the comparator 21 compares the voltage across the battery 9 with the reference value Vref.

When the voltage across the battery 9 reaches a predetermined minimum value V1 < Vref, the output of the threshold comparator 21 is brought to a condition such that the switch element 19 is made fully conductive. The current can thus flow from the positive terminal 6 towards the battery 9, the loads 10, 11 (if they are connected by means of the switches 12, 13), and the capacitor 20 connected in parallel with the battery 9. The current supplied by the alternator charges the capacitor 20 and the voltage across the battery 9 and the loads 10, 11 starts to increase. The switch 19 remains conductive until the voltage across the battery 9 has risen to a predetermined maximum value V2 > Vref, at which value the output of the threshold comparator 21 ceases to keep the switch 19 conductive, causing it to open.

The capacitor 20 is then discharged into the loads 10, 11 and the voltage across the battery 9 falls until it reaches V1 < Vref; at this point, the cycle bust described starts again.

The regulator thus operates by keeping the voltage across the users 10, 11 and the battery 9 between the minimum and maximum values V1 and V2 which are close to the nominal voltage Vbatt of the battery.

Figure 3 shows, purely by way of indication, the curve of the voltage across the loads 10, 11, the battery 9 and the capacitor 20.

The capacitor 20 is preferably formed with the use of supercapacitor technology: for example, a capacitor with a capacitance of 2 farads and an internal resistance of less than 100 milliohms is used. With such a capacitor and with an absorbtion of 100 amperes by the loads, a switching frequency of the switch 19 of the order of tens of Hz is obtained.

A conventional mechanical switch or a static switch formed by semiconductor technology (MOS transistors) may thus be used equally well for the switch 19.

The voltage regulator according to the present invention is simple and compact and has the considerable advantage that it is free of radio-frequency emissions.

Naturally, the principle of the invention remaining the same, the details of construction and forms of embodiment may be varied widely with respect to those described and illustrated, without thereby departing from the scope of the present invention.

Claims

1. A voltage regulator, particularly for use in association with an electrical generator (1, 2, 3) supplying a direct current in a vehicle with a combustion engine, characterized in that it comprises, in operative combination:
   - switching means (19) for selectively enabling and preventing the flow of current between the electrical generator and current-user means (10, 11);
   - capacitor means (20) connected in parallel with the current-user means (10, 11),
   - voltage comparison means (21) operatively connected to the switching means (19) for comparing the voltage across the capacitor means (20) with a reference value (Vref) and controlling the conduction and cutting-off of the switching means (19) so as to keep the voltage across the capacitor means (20) within a predetermined range of values (V1, V2).

2. A regulator according to Claim 1, characterized in that the switching means (19) comprise electromechanical switch means.

3. A regulator according to Claim 1, characterized in that the switching means (19) comprise semiconductor switching means.

4. A device according to Claim 3, characterized in that the semiconductor switching means comprise at least one MOS transistor.

5. A regulator according to any one of Claims 1 to 4, characterized in that it comprises further capacitor means (4) connected in parallel with output terminals (5, 6) of the electrical generator (1, 2, 3).

6. A regulator according to Claim 5, characterized in that the further capacitor means comprise a capacitor (4) having a capacitance of the order of hundreds of microfarads.

7. A regulator according to Claim 1, characterized in that the capacitor means comprise a capacitor (20) formed with the use of technology known as supercapacitor technology.

8. A regulator according to Claim 1 or Claim 7, characterized in that the capacitor means (20) have a capacitance greater than one farad.

9. A regulator according to any one of the preceding claims, characterized in that the reference value (Vref) is generated by reference-voltage generator means (22) operatively connected to a first input of the voltage-comparison means (21).

10. A regulator according to any one of the preceding claims, characterized in that it comprises voltage-divider means (7, 8) connected in parallel with the capacitor means (20), the voltage at an intermediate terminal of the voltage-divider means (7, 8) being indicative of the voltage across the capacitor means (20), the intermediate terminal being connected to a second input of the voltage-comparison means (21).

11. A regulator according to any one of the preceding claims, characterized in that the voltage-comparison means (21) can:
 - make the switching means (19) conductive when the voltage across the capacitor means (20) reaches a first predetermined voltage value (V1),
 - cut off the switching means (19) when the voltage across the capacitor means (20) reaches a second predetermined voltage value (V2) greater than the first predetermined voltage value (V1).

12. A regulator according to any one of Claims 1 to 10, characterized in that, the vehicle comprising a voltage source (9) connected in parallel with the current-user means (10, 11), the reference value (Vref) is selected so that the voltage across the voltage source (9) is kept near the nominal voltage (Vbatt) of the voltage source (9).

13. A regulator according to Claims 11 and 12, characterized in that the first and second predetermined voltage values (V1, V2) are selected so as to keep the voltage across the voltage source (9) near to the nominal voltage (Vbatt).

14. A regulator according to Claims 11 to 13, characterized in that the first predetermined voltage value (V1) is lower than the nominal voltage (Vbatt) and the second predetermined voltage value (V2) is higher than the nominal voltage (Vbatt).

15. A regulator according to any one of the preceding claims, characterized in that the voltage-comparison means (21) comprise a voltage comparator.

16. A regulator according to any one of the preceding claims, characterized in that the voltage source (9) comprises a battery and in that the nominal voltage is the nominal voltage (Vbatt) of the battery.

17. A regulator according to any one of the preceding claims, characterized in that the capacitance of the capacitor means (20) and the voltage range given by the difference between the first and second predetermined voltage values (V1, V2) are selected so that the switching frequency of the switching means (19) in use is of the order of tens of Hz.

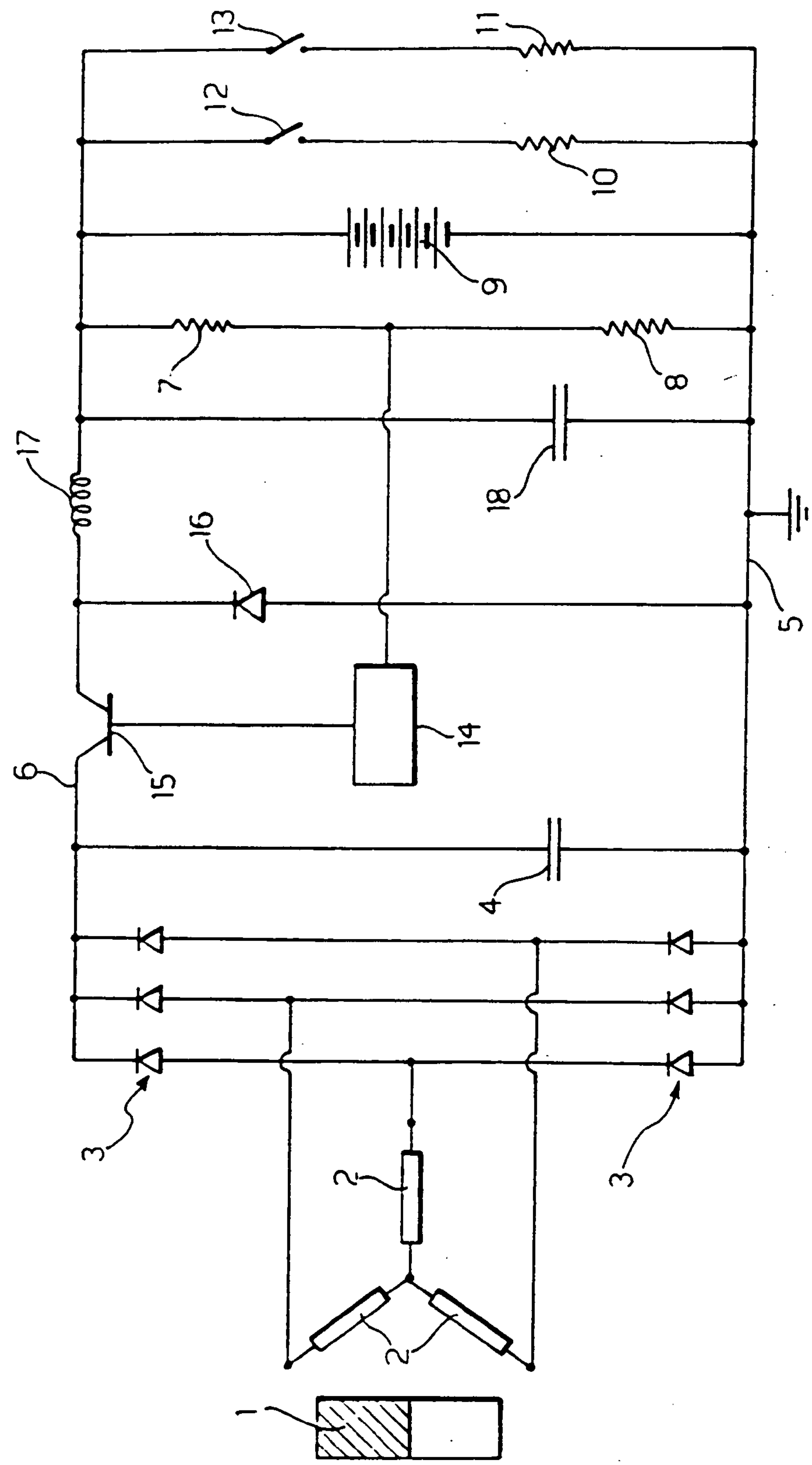


FIG. 1

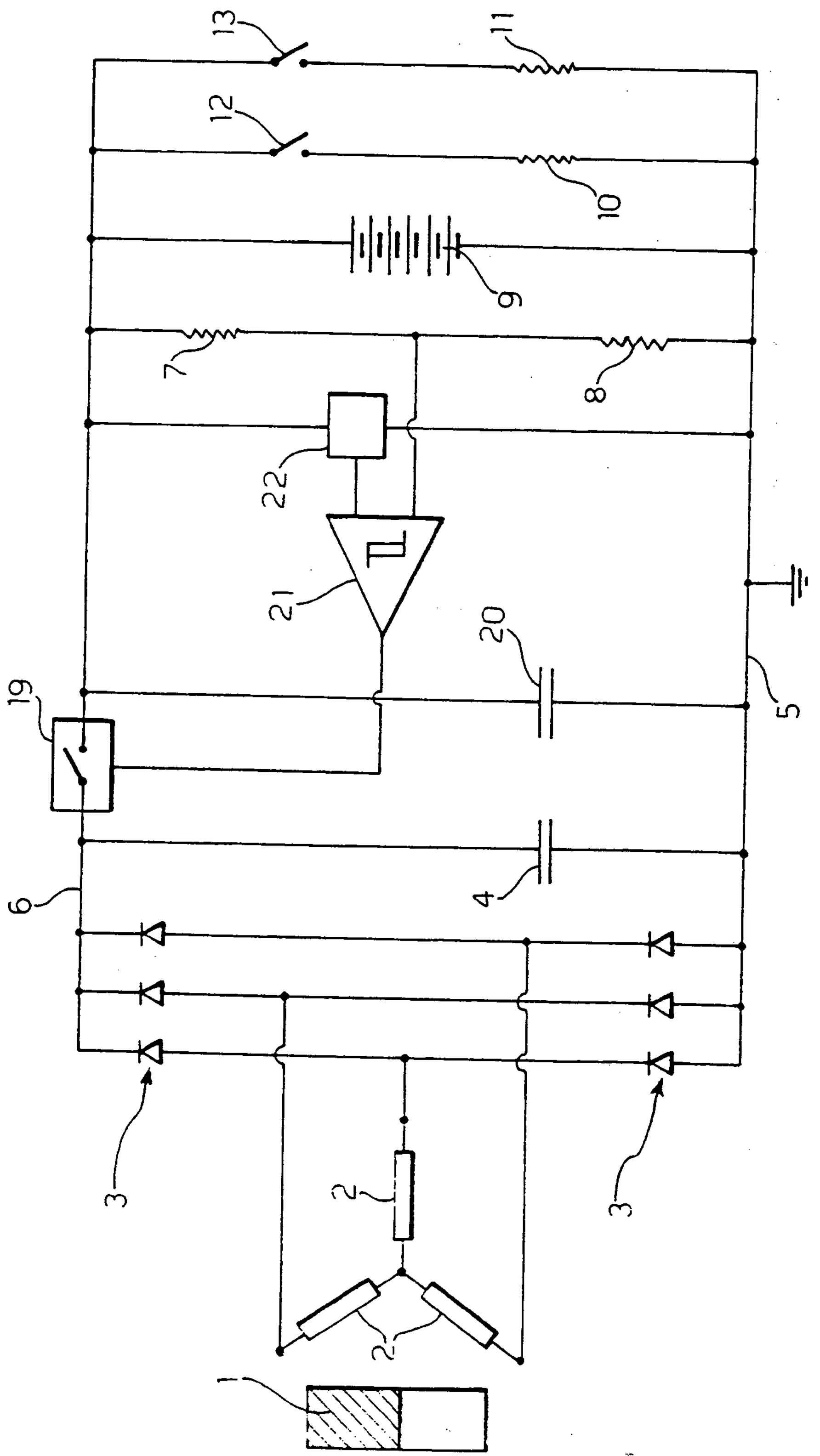


FIG. 2

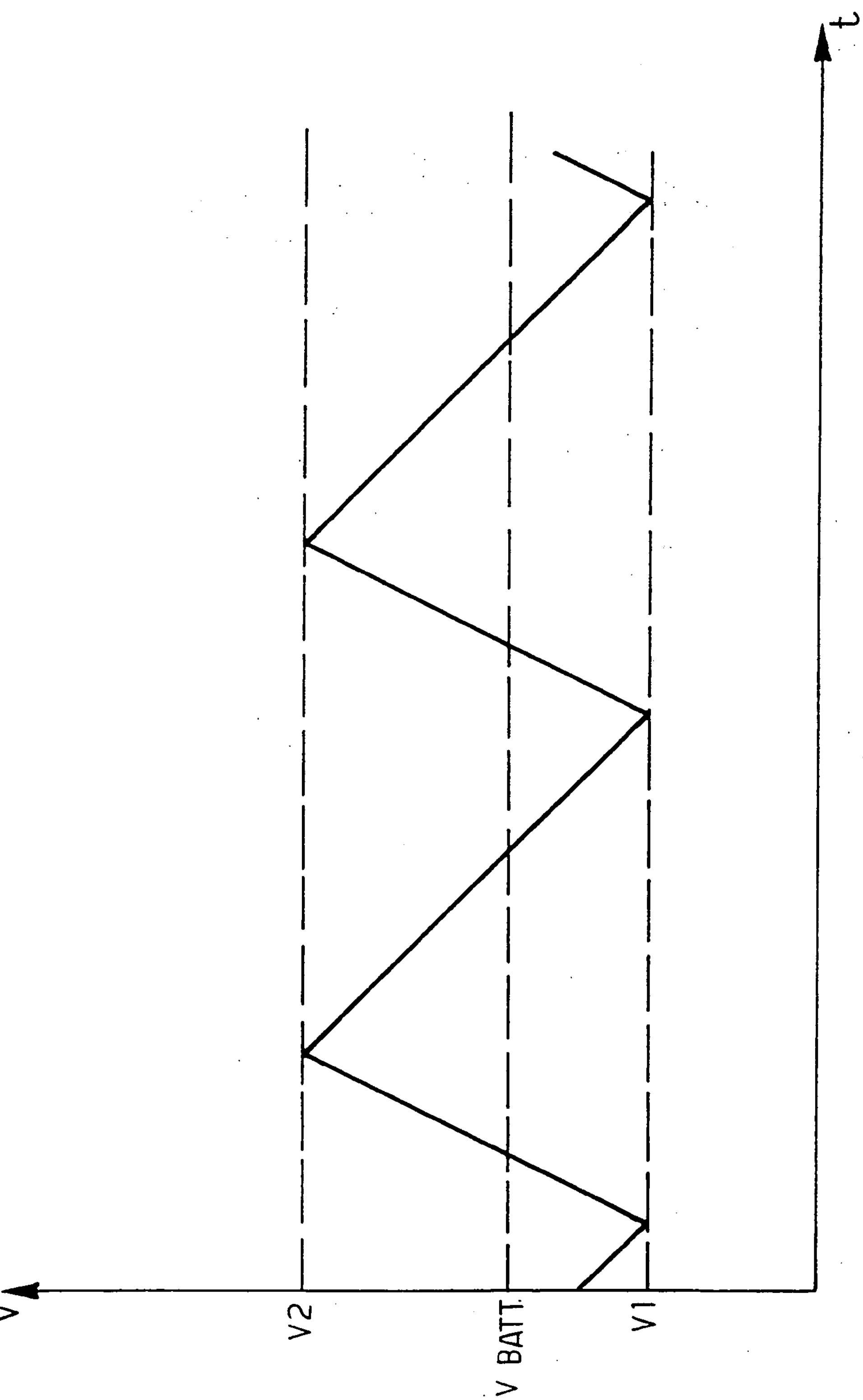


FIG. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 11 7028

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
Y	FR-A-2 533 375 (REGIE NATIONALE DES USINES RENAULT)	1	H02J7/14
A	* page 3, line 36 - page 4, line 15 *	3,5, 9-11,15, 16	
	* page 5, line 16 - page 8, line 16; figures 1,4 *		

Y	WO-A-92 12563 (MOTOROLA)	1	
A	* page 3, line 10 - page 6, line 33; figures 1-3 *	7	

A	CH-A-403 026 (BOSCH) * page 1, line 52 - page 3, line 51; figures 1,2,4 *	1-4,9-14	

A	GB-A-2 015 212 (NADA ELECTRONICS)	1,3,5, 11-14	
	* page 1, line 63 - page 2, line 40; figures 1,2 *		

A	US-A-5 153 497 (EIDEN) * column 2, line 20 - column 4, line 45; figure 1 *	1,2,9-12	**TECHNICAL FIELDS SEARCHED (Int.Cl.5)** H02J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	8 February 1994	Calarasanu, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

PAPER

Multifuel Fuel-Cell Energy System for Telecommunications Cogeneration System

XP-000790246 V2334B

Yutaka KUWATA†, Tetsuo TAKE†, Tadahito AOKI††, *and* Tsutomu OGATA††, *Members*

p. 2176-2182 = (7)   p.d. 11-1998

SUMMARY A highly reliable and highly efficient fuel-cell energy system is being developed that can run on various fuels and is suitable for a cogeneration system for telecommunications facilities. In this system, electrical power supplants the mains power and heat energy is used for air conditioning. Using this fuel-cell power plant as an emergency generator and ensuring the reliability of telecommunications requires the use of alternate fuels. This plant can run on liquefied petroleum gas (LPG) if the pipeline gas supply stops. Fuel substitution characteristics, and DC and AC interconnection characteristics have been experimentally demonstrated for connections by using a 200-kW phosphoric acid fuel cell and a 150-kW engine generator.

key words: *multifuel fuel-cell, cogeneration, emergency generator, phosphoric acid fuel cell*

1. Introduction

Fuel cells are remarkably efficient, clean energy generators that are expected to be used in cogeneration systems for telecommunications in the near future.

In a telecommunications building, the amounts of electrical energy consumed by the telecommunications equipment is usually balanced well with that used by air conditioners. Because it is necessary to cool telecommunication equipment throughout the year, a cogeneration system is suitable for use in telecommunication buildings [1], [2].

Conventional fuel-cell cogeneration systems used in hospitals and factories supply electrical power to lights, pumps, etc., and heat energy for space heating and hot water [3]. The pipeline-gas is used widely as the fuel for the fuel-cells. However, the supply of pipeline-gas may be interrupted due to disasters, such as earthquakes, and accidents. If this happens, the conventional fuel-cell cogeneration systems cannot continue generating output power.

In most telecommunications buildings, an engine generator is installed to provide electrical power for the equipment and the air conditioners during power failures. When the mains power fails, however, the conventional fuel-cell cogeneration system cannot share the load with the engine generator because of the wide variation in output frequency of the engine generator.

A fuel-cell energy system for telecommunications cogeneration systems should be as efficient and reliable as conventional power feeding and cooling systems for telecommunications. It must be reliable enough that it can continue to supply electrical and heat energy when the mains power or pipeline gas fail.

We have therefore been developing a fuel-cell system that can run on various fuels and that supplies generated electrical energy to the equipment in cooperation with the mains power. The recovered heat energy is used to cool the equipment. If the pipeline gas supply stops, the fuel-cell system switches to an alternate fuel and continue to supply power.

When the mains power fails, the fuel-cell system shares the load with the engine generator. Therefore, it can be used as an additional emergency generator, thus decreasing investment costs.

Thus, this highly reliable and highly efficient multifuel fuel-cell system is a cost-effective telecommunications energy system.

2. Basic Configuration of Multifuel Fuel-Cell Energy System

The fundamental configuration of our multifuel fuel-cell energy system for telecommunications is shown in Fig. 1. This cogeneration system that supplies generated electrical power to telecommunications equipment and supplies generated heat energy to air conditioners. Fuel gas and steam are supplied to a reformer, which contains a catalyst. The steam-reformed gas,

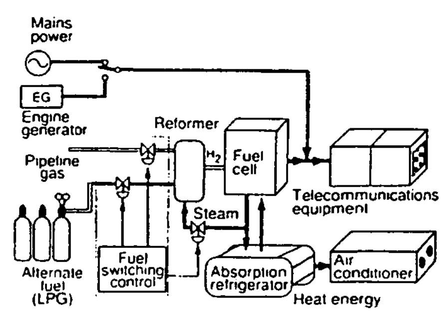


Fig. 1 The fundamental configuration of multifuel fuel-cell energy system for telecommunications.

Manuscript received July 1, 1997.
Manuscript revised February 12, 1998.

† The authors are with NTT Integrated Information & Energy Systems Laboratories, Musashino-shi, 180-8585 Japan.
†† The author is with NTT Power and Building Facilities Inc., Musashino-shi, 180-0012 Japan.

which contains a large amount of hydrogen, is then supplied to the fuel cell. The fuel cell is a generator; it uses the electrochemical reaction between the hydrogen from the fuel gas and the oxygen from the air to produce electrical and heat energy.

The fuel-cell's electrical output is supplied in parallel with the mains power. Since the mains power can respond quickly to fluctuations in the load, the fuel-cell output can be kept constant. When the mains power fails, the engine generator starts up and the fuel-cell output is fed to the telecommunications equipment along with the engine-generator output. If the pipeline gas supply stops, the fuel for the fuel-cell power plant is switched to the alternate fuel and power continues to be supplied. Such a multifuel fuel-cell power plant is therefore useful as an emergency generator.

This system converts energy from fossil fuel into energy suitable for use by telecommunications equipment and its cooling systems more efficiently than conventional systems whose energy is wholly supplied from an external source. It can also decrease the required engine generator capacity and hence its cost.

3. Multifuel Fuel-Cell Energy System for Telecommunications Co-generation System

The configuration of our multifuel fuel-cell energy system for a telecommunication cogeneration system is shown in Fig. 2. The fuel-cell power pack, the DC and AC interconnection equipment, and an absorption refrigerator are installed in the power room. An engine generator is provided for emergency use.

Although the electrical consumption in a telecommunications building is constantly fluctuating, it is not advisable to design the fuel-cell capacity to match the peak value of the required power, because if the fuel cell operates at the maximum power, than the electrical and heat energies will be maximized. The recovered heat energy also reaches its maximum at the maximum electrical output and decreases with the magnitude of the output. Therefore, power is supplied from the mains power to operate the fuel cell at maximum power and compensate for variations in the load.

The fuel gas flow is regulated to ensure stable fuel-cell current. However, the fuel supply has a much slower response time than the electrical output current. Because the mains power may fail and the load may vary, the variation in fuel-cell current must be limited to avoid fuel-cell deterioration. The fuel-cell current is kept at a constant level, and variations in load are provided for by the mains power or by the engine generator.

The waste heat energy recovered from the fuel-cell power plant is used by the absorption refrigerator to cool the telecommunications equipment.

The system can also deal with periodic interruptions for maintenance or ones caused by breakdown because the mains power backs up the fuel-cell output.

In a conventional fuel-cell system, there is an inverter in the power pack and its output is supplied to the AC load. In our energy system, a converter converts the fuel-cell DC voltage to stable DC voltage, thus achieving very efficient and very reliable DC power. The fuel-cell output follows two paths [4]: part passes through the converter to provide DC power for the telecommunications equipment, and the rest passes through an inverter to provide AC power for air conditioners, computers, etc.

As shown in Table 1, when the mains power is normal, the fuel-cell power plant shares the load with

Table 1 Power supply modes.

		Mains power	
		supply	stop
Pipeline gas	supply	· fuel cell (pipeline gas) · mains power	· fuel cell (pipeline gas) · engine generator
	stop	· fuel cell (LPG) · mains power	· fuel cell (LPG) · engine generator

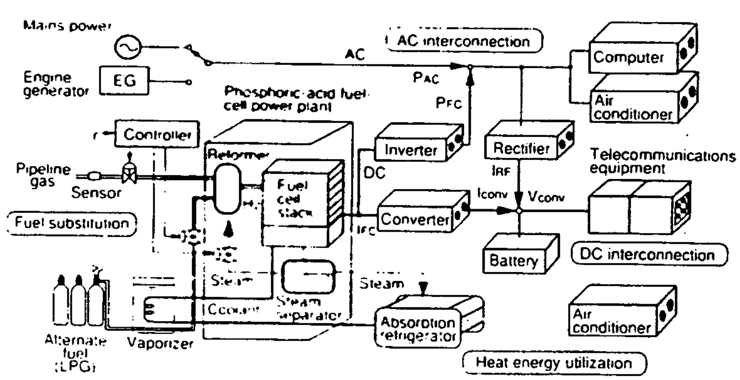


Fig. 2 Multifuel fuel-cell energy system configuration for telecommunications cogeneration system.

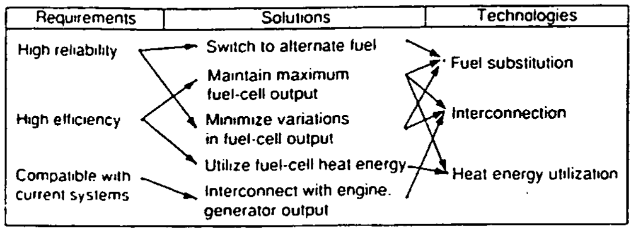


Fig. 3 Requirements, solutions, and technologies for achieving reliability and efficiency.

the mains power. If the mains power fails, the engine generator starts up, and the fuel-cell power plant begins sharing the load with the engine generator. If the pipeline gas supply stops, the fuel for the fuel-cell power plant is switched to the alternate fuel(LPG), and power continues to be supplied.

Better fuel substitution and energy utilization technologies must be developed in order to increase the reliability and efficiency of the total power system, and to achieve compatibility with today's power systems. These requirements, their solutions, and the relevant technologies are summarized in Fig. 3.

4. Fuel Substitution Technology

Pipeline gas is a suitable fuel for fuel cells because it is easy to procure and its steam-reforming technology is well established. However, its supply may be interrupted by disasters like earthquakes or accidents. Using the fuel-cell system as an emergency generator and ensuring the reliability of telecommunications requires the provision of an emergency fuel.

Liquefied petroleum gas(LPG) is the best choice for such a fuel because it is easy to acquire, store, and transport, and it can be conveniently steam-reformed. LPG must be steam-reformed in the same way as pipeline gas to generate the hydrogen needed for the fuel-cell reaction. It is unrealistic to provide an additional reformer for LPG in view of the installation space and cost, so LPG should be steam-reformable using the same reformer as used for pipeline gas.

We previously studied the steam-reforming characteristics of the Ni-Al_2O_3 catalyst, the most common catalyst for steam-reforming pipeline gas, for pipeline gas and LPG. The results showed that both pipeline gas and LPG can be steam-reformed to their equilibrium compositions by using the Ni-Al_2O_3 catalyst, so the same reformer can be used. When the fuel is changed from pipeline gas to LPG, the heat supply must be reduced to avoid a rise in the reformer temperature and to prolong the lifetime of the catalyst. On the other hand, the steam supply must be rapidly increased when the fuel is changed from pipeline gas to LPG, so the fuel-cell system requires a large steam separator.

In our system, we use a new catalyst to decrease

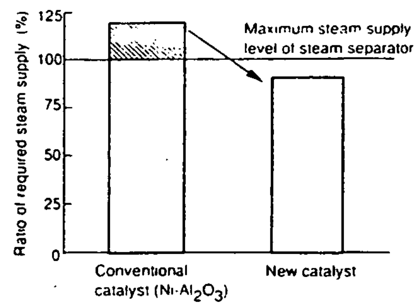


Fig. 4 Comparison of amount of reforming steam needed for LPG (output power: 200 kW).

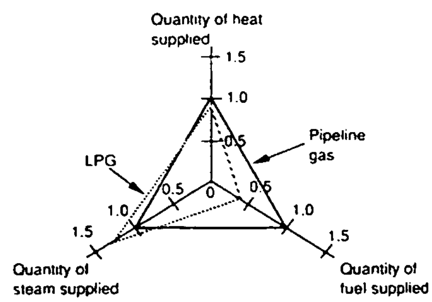


Fig. 5 Possible supply combinations (normalized by pipeline gas).

the amount of reforming steam needed. As shown in Fig. 4, the new catalyst requires much less steam supply than the conventional Ni-Al_2O_3 catalyst.

By using this new fuel-substitution technology, therefore, LPG can be automatically steam-reformed in the same reformer and steam separator that are used for pipeline gas.

Figure 5 shows the supply combinations we use for fuel substitution. As discussed above, when the fuel supply is changed over from pipeline gas to LPG, the fuel and reforming-steam supply must be controlled to maintain a constant fuel-cell output power and to prolong the life of the catalyst. The new catalyst is used to decrease the amount of reforming steam needed. If the pipeline gas stops, the fuel for the fuel-cell power plant is switched to LPG to ensure a continuous power supply. Figure 6 shows the test results for changing the fuel supply over from pipeline

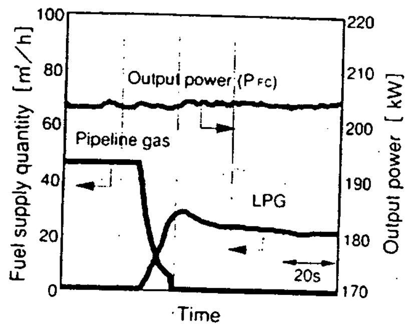


Fig. 6 Effects of fuel substitution on output power.

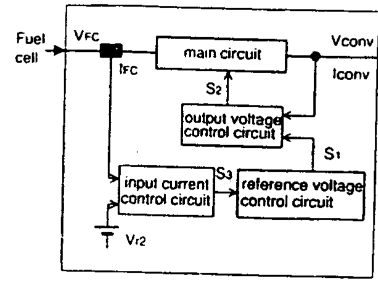


Fig. 7 Converter control circuit.

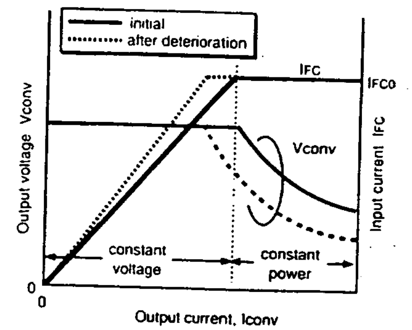


Fig. 8 Converter input and output characteristics.

gas to LPG. Despite this fuel change, the fuel-cell output power remained constant at about 200 kW. The experimental results for changing from LPG to pipeline gas were similar. This demonstrates that the fuel substitution was successful.

5. Interconnection Technology

While both DC and AC-interconnection technologies has been demonstrated in a field test [5], better interconnection technologies must be developed to increase the efficiency and reliability of the total energy system and to extend the lifetime of the fuel cells.

5.1 DC Interconnection

In a DC interconnection system, the converter converts the fuel-cell voltage to a stable DC load voltage. The fuel-cell power is supplied to the load in parallel with the rectifier output. When the mains power is normal, the rectifier converts a mains AC voltage to a stable DC load voltage. Thus, the fuel cell power can be held constant by a quick response from the mains power against fluctuations in the load. If the mains power fails, the rectifier output falls to zero. Therefore, the converter output is connected in parallel with that of the backup battery.

A conventional DC interconnection converter controls its output current constant to restrict the variation in fuel-cell current so as to avoid fuel-cell deterioration [4], [5]. When the rectifier output voltage varies due to mains power failure, the fuel-cell current fluctuates. Moreover, as the fuel-cell voltage decreases due to deterioration, its current approaches its rated value. If it exceeds its rated value, an emergency stoppage can result.

Our new DC interconnection converter maintains maximum fuel-cell current, keeping total efficiency high. Stable fuel-cell operation is thus achieved even if the AC power fails or the load varies.

As shown in Fig. 7, the converter control circuit has an input-current control circuit and a reference-voltage control circuit, in addition to an output-voltage control circuit [6]. The output-voltage control circuit compares output-voltage V_{conv} to output signal S_1 of the reference-voltage control circuit. If the output voltage drops, the converter increases the output voltage by increasing signal level S_2 of the output-voltage control circuit. In this manner, the output voltage is kept at constant.

When the input current reaches reference level V_{r2} of I_{FC0}, the input-current control circuit decreases input signal S_3 of the reference-voltage control circuit. As S_3 decreases, the signal level of S_1 decreases, and the output voltage decreases to maintain input current I_{FC0}. As a result, even if the converter output voltage varies, the fuel-cell current is maintained at a constant value.

As shown in Fig. 8, when input current I_{FC} is under rated current I_{FC0} at startup or light-load condition, converter output voltage V_{conv} is kept constant. Input voltage V_{FC} decreases as input current I_{FC} increases as a result of the fuel-cell characteristics. Because the converter controls its output to keep input current I_{FC} at the constant rated value, converter input power P_{FC} is restricted to the maximum rated value. Output power P_{conv} is thus kept constant. Therefore, the fuel-cell current is limited to the constant rated value, I_{FC0}, and the converter operates in the constant power region shown in Fig. 8.

The steady-state and transient DC interconnection characteristics are listed in Table 2 and shown in Fig. 9, respectively. As converter input voltage V_{FC} decreases, the converter input current remains constant.

and its output current is proportional to the input voltage in the steady state (see Table 2).

Figure 9 shows DC interconnection characteristics when the mains power fails. The converter output is connected in parallel with the backup battery. When the mains power fails, the converter voltage falls to the battery voltage, and both the converter and the battery supply power to the load. Because of the constant power operation, the converter input current (I_{FC}: fuel cell current) is kept constant. These results demonstrate the good DC interconnection characteristics.

Table 2 DC interconnection characteristics (steady-state condition).

	Initial	After deterioration
V_{FC} (V)	290	270
I_{FC} (A)	33.4	
V_{conv} (V)	51.8	51.5
I_{conv} (A)	172	163
I_{RF} (A)	87	96
I_{load} (A)	259	

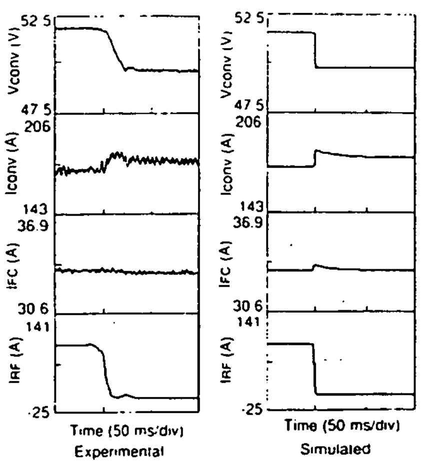
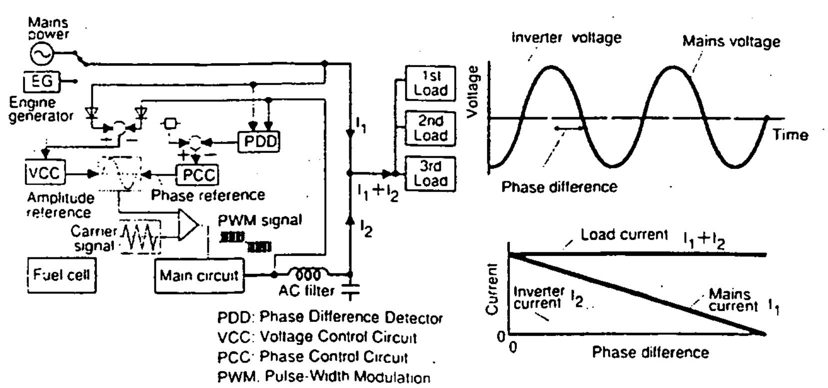


Fig. 9 DC interconnection characteristics of output voltage variation ($V_{FC}=290$ V, $I_{FC0}=33.4$ A).

5.2 AC Interconnection

In an AC interconnection system, the fuel-cell output is fed to computers or air conditioners through the inverter along with the commercial AC power. The inverter controls its output voltage to restrict the variation in fuel-cell output power so as to avoid fuel-cell deterioration. During AC interconnection, the inverter output power is kept constant by controlling the inverter voltage.

A block diagram of the inverter and the principle of load-sharing control are shown in Fig. 10. The pulse-width-modulation (PWM) technique is used to control the output voltage of the inverter. In the controller, a voltage-control circuit (VCC) and a phase-control circuit (PCC) determine the amplitude and the phase of the reference sinusoidal signal by using the voltage and phase difference signals between the commercial AC voltage and the inverter output voltage. The PWM signal can then be generated by comparing the reference sinusoidal signal with the carrier signal. When the phase difference increases, the inverter output current increases and the commercial AC current decreases. Fuel-cell output thus remains constant despite load variations. Because of voltage differences between the phases of the commercial AC line, this control operation is individually performed for each phase of the inverter. When the inverter starts up, the inverter output power increases at a constant rate. The output power linearly reaches its rated output power. After start-up, the inverter output remains constant in spite of variations in the load power. The AC interconnection characteristics were previously measured in field tests [5]; they demon-



(a) Inverter (b) Principle of load-sharing control

Fig. 10 Inverter and principle of load-sharing control.

strated that the fuel-cell output power can be kept constant while load-power variations are handled by the mains power.

If the mains power fails, the fuel-cell power plant supplies its power to the load as an emergency generator. When the load capacity is much larger than the capacity of the fuel-cell power plant, the engine generator is also used. Figure 11 shows the AC interconnection characteristics when the mains power fails. The engine generator starts up and supplies its power to the initial load. Variations in load are compensated for by the engine generator. After the generator output has reached a sufficient level, the inverter begins sharing the load with the generator, increasing its load gradually. As the inverter output increases, the engine generator output decreases. When the generator output reaches a sufficiently small level, the second load is connected. The load variation is compensated for by the engine generator and the fuel-cell output remains constant. After the engine generator has been supplying its power to the second load, the inverter begins to gradually increase its load and continues increasing it until it reaches its rated power. Therefore, the fuel-cell power plant can operate well as an emergency generator sharing the load with the engine generator.

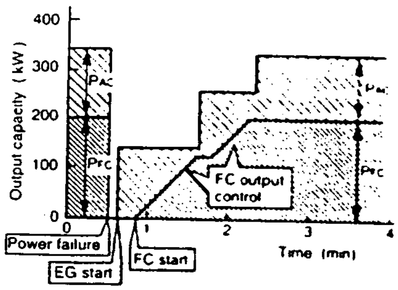


Fig. 11 AC interconnection characteristics when mains power fails.

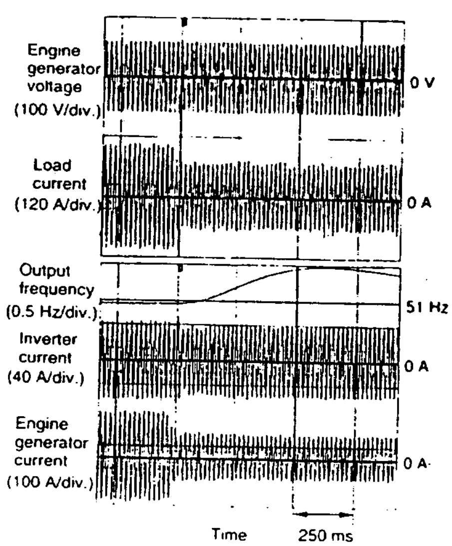


Fig. 12 AC interconnection characteristics when engine generator is interconnected.

Figure 12 shows the AC interconnection characteristics when the load current decreases. The output frequency of the engine generator increases gradually and the inverter controls its phase difference to maintain the inverter output at a constant level. Therefore, the inverter current remains constant and the engine generator current decreases even when the engine generator frequency varies widely.

6. Heat Energy Utilization Technology

In a telecommunications building, where it is necessary to cool telecommunications equipment all year round, the heat energy of the fuel cell is supplied to an absorption refrigerator. Figure 13 shows fuel-cell energy use in such a building. Heat energy from the fuel cells is obtained from the coolant used for cooling the fuel cell stack and from the exhaust gas [7]. Steam generated from the coolant is directly supplied to a high-temperature generator heat source. The heat recovered from the fuel-cell exhaust gas is supplied to a low-temperature generator heat source.

The fuel-cell stack coolant, which recovers the reaction heat produced when electricity is generated by the fuel cells, is fed into a steam separator. The steam produced here is supplied to a reformer, where it is used for reforming the fuel.

The direct steam heat recovery method is used to keep the heat recovery temperature high and to avoid the need to use a heat exchanger. Twenty-three percent of the fuel energy is converted to steam. To prevent the fuel cells from deteriorating and to maintain high electrical efficiency, the temperature of the fuel cell stack coolant should be kept constant. It can be accurately controlled and the pressure of the absorption refrigerator can be kept high even when low-temperature water is being fed to the coolant.

The low-temperature generator in the absorption refrigerator generally requires a relatively high-temperature input, so the absorption refrigerator can-

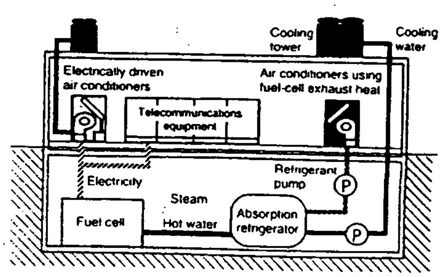


Fig. 13 Fuel-cell energy use in telecommunications.

not use extra heat energy that is supplied at a relatively low temperature. However, an absorption refrigerator that operates all year round in a telecommunications building can use the relatively low-temperature heat energy and increase the heat recovery ratio when the cooling water temperature decreases. The amount of heat recovered from the exhaust gas is estimated to be 18% of the fuel energy.

7. Conclusion

The proposed multifuel fuel cell energy system is suitable as a cogeneration system for telecommunications. It is a very efficient and reliable energy system. Fuel substitution characteristics, and DC and AC interconnection characteristics have been experimentally demonstrated for connections by using a 200-kW phosphoric acid fuel cell and a 150-kW engine generator. Demonstrations of this system have been conducted at the NTT R & D Center in Musashino.

Acknowledgments

We express our appreciation to Mr. Maki Ishizawa, Mr. Hiroshi Amanuma, Mr. Masahito Adachi, and Mr. Shizuo Furubo of the NTT Integrated Information & Energy Systems Laboratories for their advice and encouragement.

References

[1] T. Koyashiki and K. Yotsumoto, "Advanced fuel cell energy system for telecommunications use," Proc. of INTELEC '92, pp. 1-2, 1992.

[2] K. Oshima, T. Uekusa, M. Ishizawa, and T. Kameyama, "Technology for supplying and utilizing fuel cell heat energy," NTT Review, vol. 6, no. 2, pp. 59-64, March 1994.

[3] T. Ito, S. Ohashi, and H. Yoshida, "Experience on PAFC field test of real customer sites," Proc. of 2nd Fuel Cell Symposium, A1-6, pp. 29-34, 1992.

[4] Y. Kuwata, R. Tanaka, and M. Iwasawa, "Combined fuel cell and commercial power system for telecommunications use," NTT Review, vol. 6, no. 2, pp. 54-58, March 1994.

[5] T. Koyashiki, R. Okada, Y. Kuwata, M. Ishizawa, and K. Oshima, "Field test on a fuel cell energy system for telecommunications equipment," Proc. of INTELEC '93, 14-B-4, 1993.

[6] Y. Kuwata, T. Babasaki, M. Iwasawa, and T. Koyashiki, "Input current controlled DC interconnection converter for fuel cell systems," Proc. of INTELEC '94, pp. 1-2, 1994.

[7] K. Oshima, T. Uekusa, M. Ishizawa, and T. Kameyama, "Technology for supplying and utilizing fuel cell heat energy," NTT Review, vol. 6, no. 2, pp. 59-64, March 1994.

Yutaka Kuwata was born in April 24, 1952. He received the B.E. degree in electrical engineering from Kyushu Institute of Technology, Japan, in 1975. Since joining NTT Laboratories in 1975, he has been engaged in developmental research on DC power supply systems, switch-mode rectifiers and fuel-cell energy systems. He is a Senior Research Engineer, Supervisor of NTT Integrated Information and Energy Systems Laboratories, Nippon Telegraph and Telephone Corporation. He is a member of IEEE.

Tetsuo Take was born on June 19, 1955. He received B.E. and M.E. degrees in Chemical Engineering from Tohoku University, Japan, in 1979 and 1981, respectively. Since joining Nippon Telegraph and Telephone Corporation in 1981, he has researched and developed lead-acid batteries and fuel cell systems. He is a Senior Research Engineer of NTT Integrated Information and Energy Systems Laboratories, Nippon Telegraph and Telephone Corporation. He is a member of the Institute of Electrical Engineers of Japan, the Catalysis Society of Japan, the Electrochemical Society of Japan, the Society of Chemical Engineers, Japan, and the Chemical Society of Japan.

Tadahito Aoki was born in November 25, 1960. He received B.E. and M.E. degrees in Electrical Engineering from Shinshu University, Japan, in 1984 and 1986, respectively. Since joining Nippon Telegraph and Telephone Corporation in 1986, he has researched and developed switched mode rectifier. He is a Senior Engineer of Research and Development Department, NTT Power and Building Facilities Inc. He is a member of IEEE.

Tsutomu Ogata was born in 1949 in Hokkaido, Japan. He was received the B. E. degree from Muroran Institute of Technology, Japan, in 1971 and the Dr. of Eng. degree from Kyushu University in 1992. Since joining Nippon Telegraph and Telephone Corporation in 1971, he has been engaged in developmental research on Telecommunications energy system, DC-DC converters, and batteries. He is a Senior Manager of Research and Development Department, NTT Power and Building Facilities Inc. He is a member of IEEE.